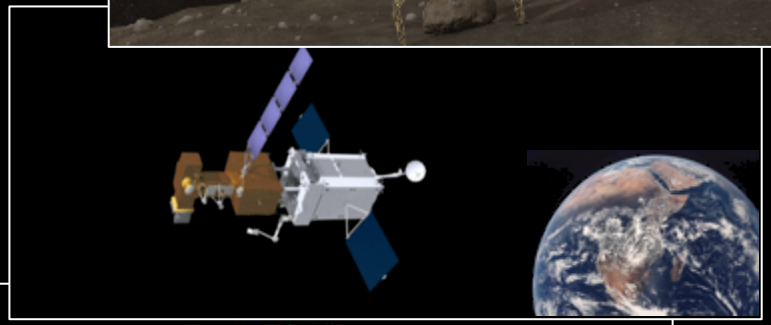
Achieving Supportability on Exploration Missions with In-Space Servicing



Presented at AIAA Space 2015
August 31, 2015

Presented by
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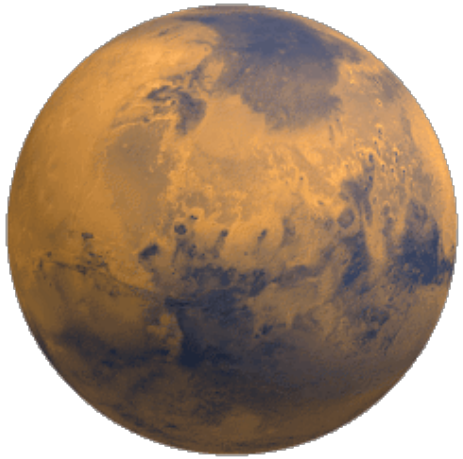
Introduction

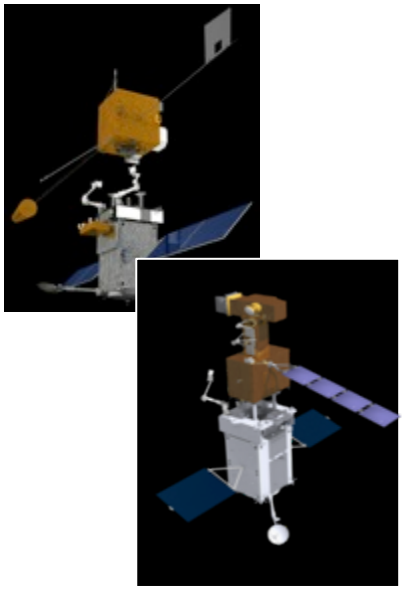
- **Why Is Servicing Important?**
  - In terms of space exploration, servicing supports mission success through reduced cost, simplified logistics, re-use of hardware, and minimizing resources
  - NASA is in various stages of planning manned and unmanned missions to an asteroid, Mars and beyond
  - Applying the concept of servicing to these missions will increase the likelihood of mission success
  - NASA is maturing core servicing technologies that support ambitious missions



Servicing Servicing Capabilities Office (SSCO)

NASA's Satellite Servicing Capabilities Office is developing servicing technologies that support exploration.

Study



Study point design notional missions with guidance from RFI responses

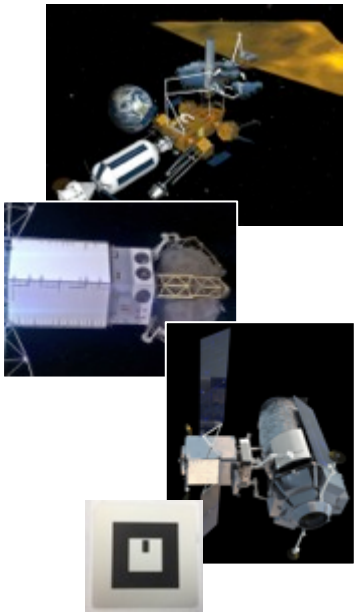
Build

Build hardware & software for experiments in orbit and on the ground

Test

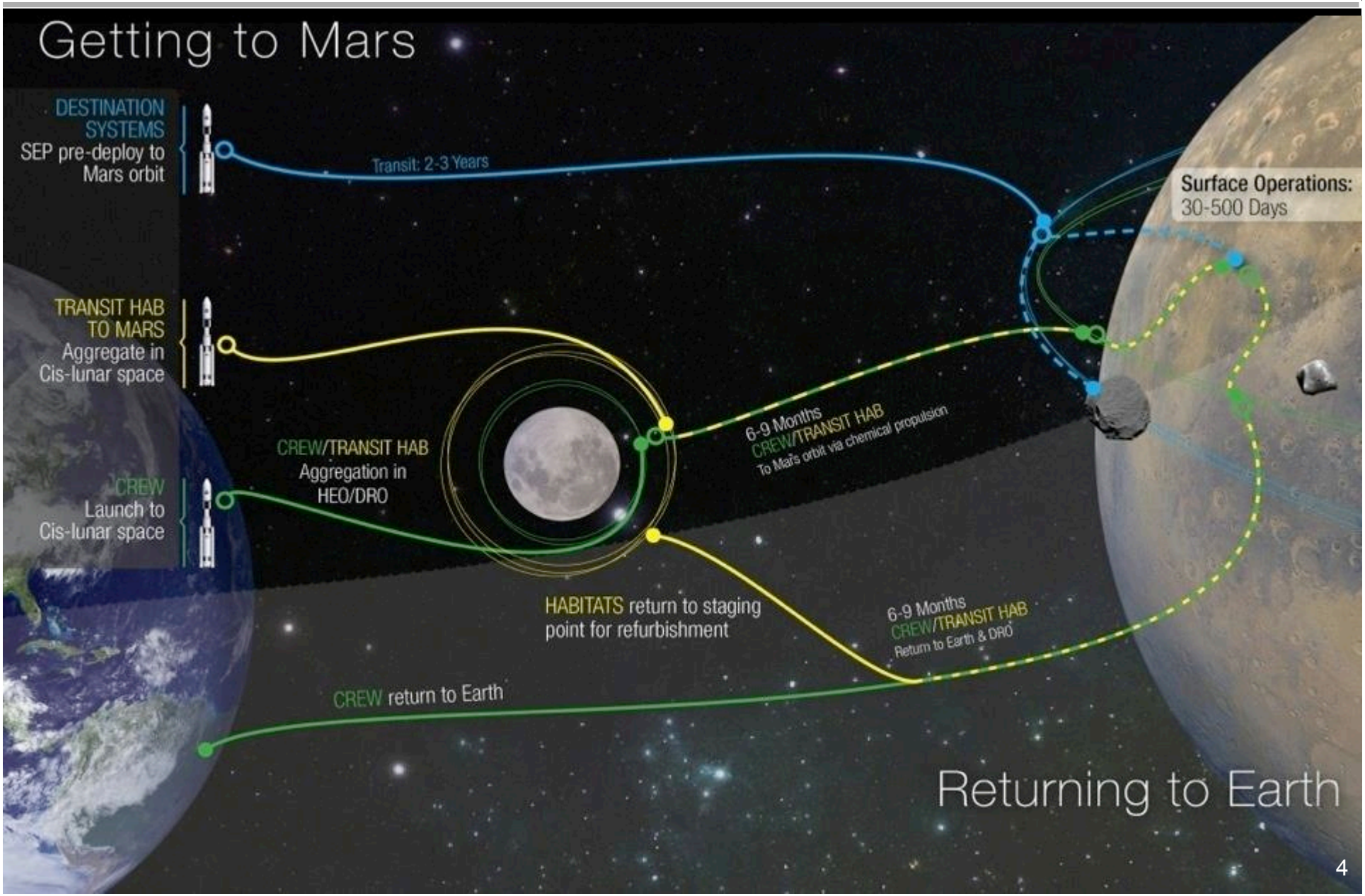
Manage technology development campaign and servicing missions

Advise

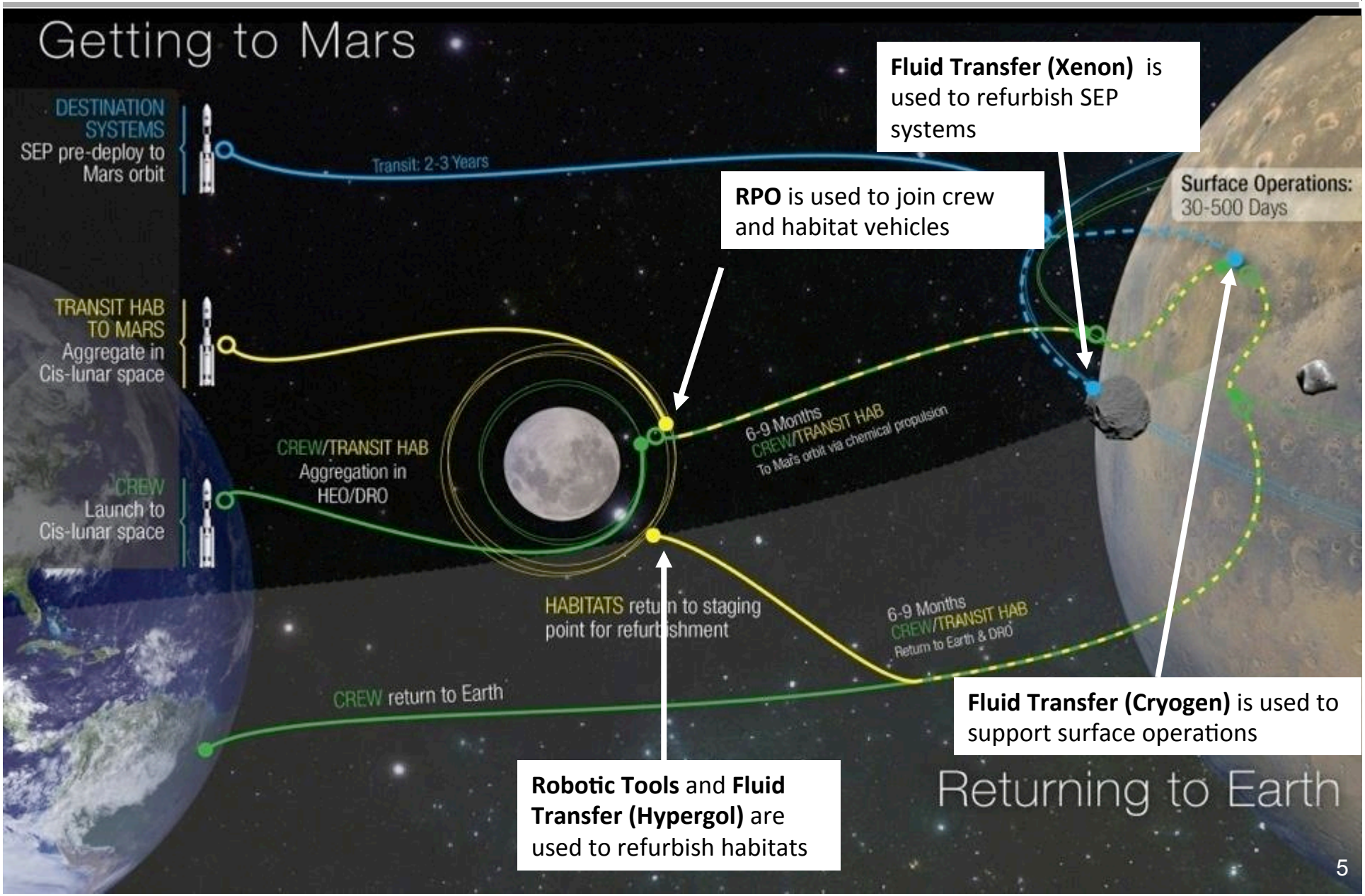


Design and advise cooperative servicing elements

NASA's Path to Mars



Technologies That Support NASA Objectives



NASA Is Maturing Critical Servicing Technologies

SSCO is rapidly maturing five key technologies that unlock servicing capabilities.

Rendezvous & Prox Ops System

High-speed, Fault-Tolerant Computing

Dexterous Robotics

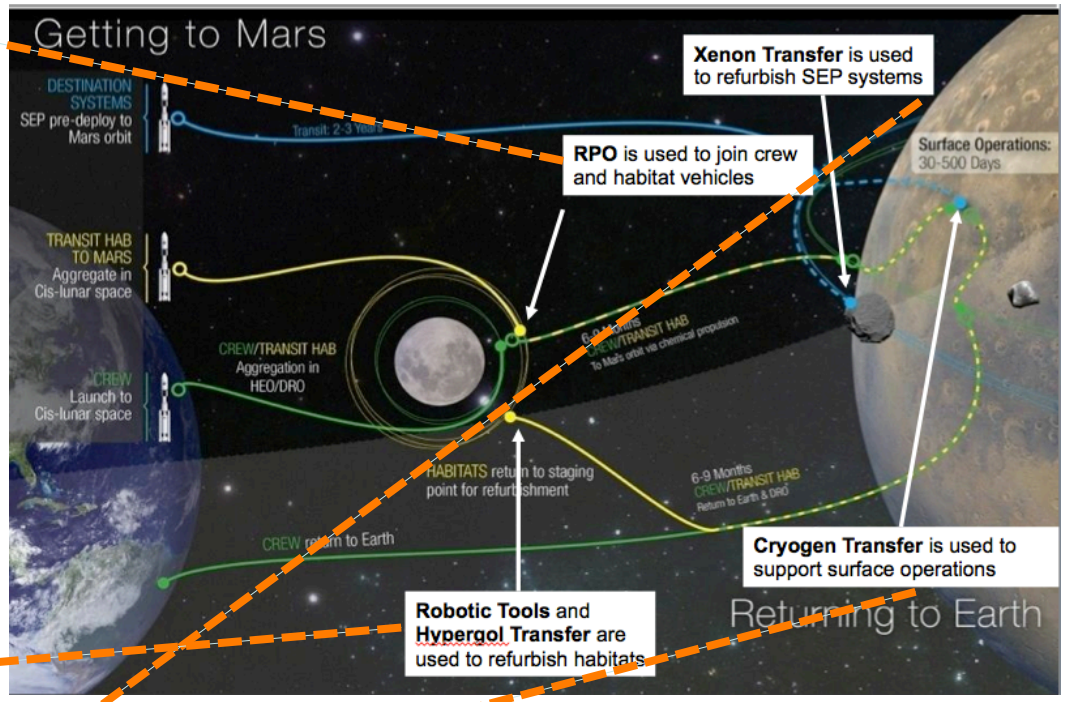
Robotic Tools

Fluid Transfer

Servicing Technologies Enhance Supportability

Our paper describes how three of these servicing technologies are building blocks for supportability.

- **Rendezvous & Prox Ops System**
- **High-speed, Fault-Tolerant Computing**
- **Dexterous Robotics**
- **Robotic Tools**
- **Fluid Transfer**



Rendezvous and Proximity Operations System

What an RPO system means to servicing

- Autonomous, real-time, relative navigation - remotely

How this capability enhances supportability

- Autonomous rendezvous breaks dependence on human-in-the-loop control
- Capability to perform terrain-relative navigation of unmanned spacecraft in remote, uncharted areas

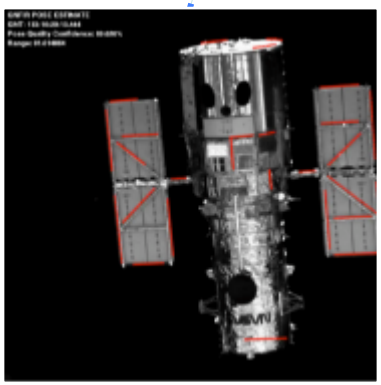
Missions that benefit

- Asteroid redirection and planetary defense
- Orion crew vehicle
- Mating of separate flight components: crew vehicle, habitat module, transfer vehicle, surface lander
- Upkeep of future spacecraft en route to Mars
- Assembly of large structures

RPO Advancements
Servicing Technology Maturation and Test Campaign

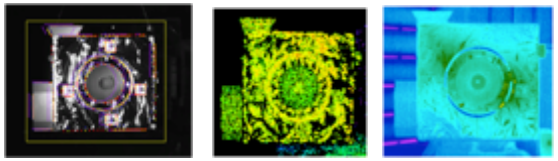
2005-2009 | **2010** | **2011** | **2012** | **2013** | **2014** | **2015** | **2016** | **2017**

Real-time 6-DOF pose of HST



GNFIR and SpaceCube (within RNS) on STS-125: non-cooperative tracking using visible camera

Proximity Sensors & Algorithms



EDU (Argon) test suite demonstrated multi-wavelength (visible, flash lidar, and long-wave infrared) sensor fusion on flight avionics

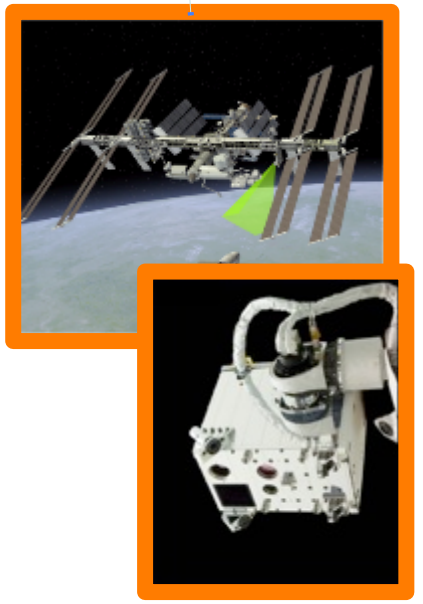
Closed Loop Testing

Final approach and capture box closed-loop demonstration

Closed Loop Testing 2

Midrange, closed-loop demonstration and high-fidelity characterization of pose algorithms and sensors

Autonomous tracking of spacecraft (Raven)



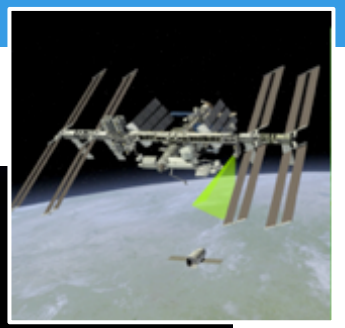
Raven demo to fly to ISS as part of DoD's STP-H5 payload

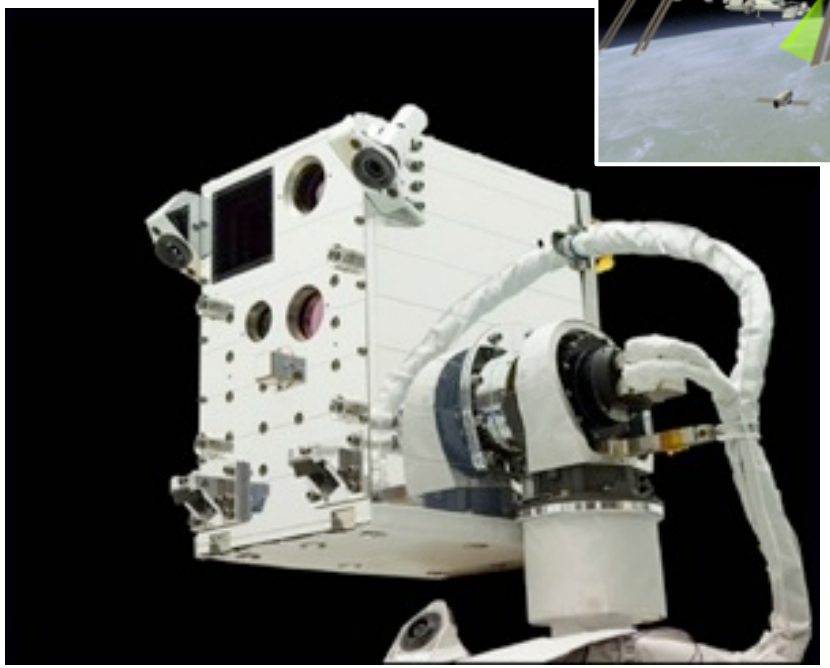
RPO Advancements
Raven: Technology Demonstration on ISS

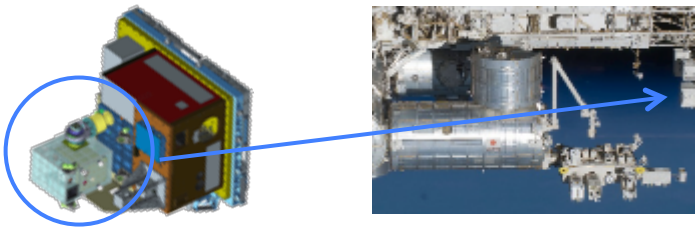
Raven is an ISS technology demonstration of system-level technologies applicable to accomplish cooperative and non-cooperative relative navigation.

Complex, but compact, hardware complement

- Two-axis gimbal provides sensor pointing
- Relative navigation sensors provide tracking in three bands – visible, long-wave IR, and short-wave lidar
- State-of-the-art pose algorithms provide relative position and attitude measurement of the visiting vehicle relative to each sensor
- High-performance avionics provide efficient, reliable, and reconfigurable computing environment
- Navigation algorithms provide an optimal estimate of the relative state – position, velocity, attitude, and rate – based on data from all the sensors







Two-year mission provides upwards of 60 relative navigation tracking events (rendezvous and departures).

Fluid Transfer and Advanced Robotic Tools

What this capability – Refueling, Replenishing, and Recharging – means to servicing

- Crew vehicles can travel greater distances
- Ability to extend the lives of assets and their instruments

How these capabilities enhance supportability

- By refueling and replenishing vehicles on journey to Mars, reduce vehicle size and consumable load
- Refuel/recharge to extend the lifespan of existing assets, deriving more value from initial investment

Missions that benefit

- Journey to Mars: rechargeable SEP systems, fuel depots
- Mars surface operations: cryogen transfer allows for propellant storage and fueling for surface departure
- Satellite fleets: life extension

Fluid Transfer and Advanced Robotic Tools
Servicing Technology Maturation and Test Campaign

2005-2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017

Oxidizer seal-less pump evaluation

Ethanol refueling on orbit

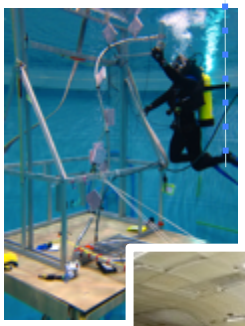
Hose tests in zero-g, NBL

Oxidizer Transfer

Propellant Transfer system

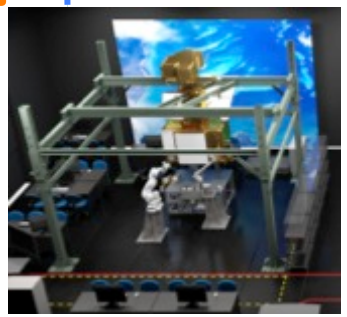
Cryo and Xenon transfer (RRM-3)

Robotic Refueling Mission demo of tools and procedures and transfer of ethanol



Neutral buoyancy and zero-g evaluations of flexible hose characteristics

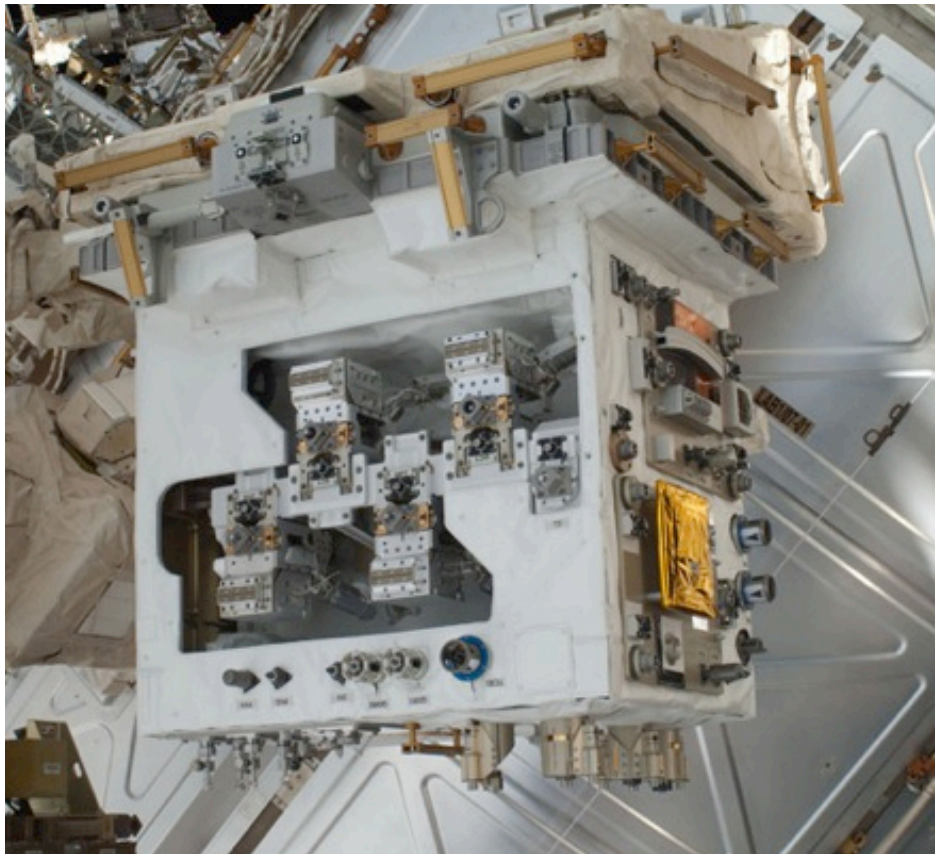
Oxidizer transfer at flight pressures, flow rates and quantities



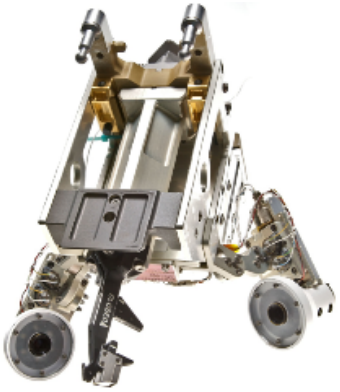
Propellant Transfer System integrated into system-level test of refueling

Demo of xenon recharge & cryogen transfer

Refueling Technologies
On-orbit Testing

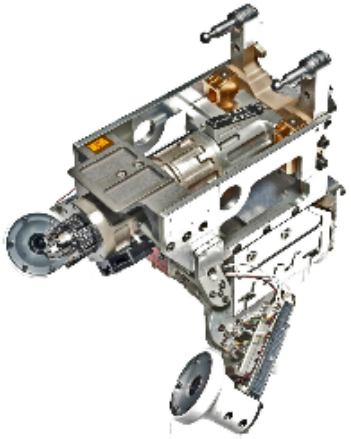


Robotic Refueling Mission module



MLI/Wire Cutter Tool

Safety Cap Tool

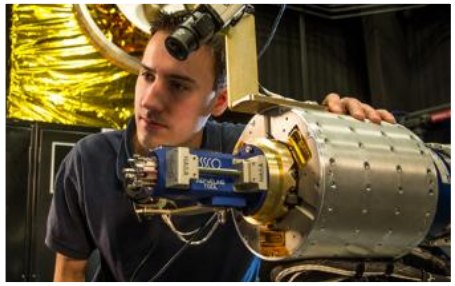


Multifunction Tool

EVR Nozzle Tool

Refueling Technologies
Ground Testing of Propellant Transfer System

- Hypergolic fluids of interest:
  - Hydrazine
  - Monomethyl hydrazine
  - Nitrogen Tetroxide
- System analysis models have been made to determine transfer timelines and include thermal loading impacts
- Over thousands of initial component level and partial propellant servicing system test runs to date
- In 2014, SSCO conducted the Remote Robotic Oxidizer Transfer test tests – a series of hypergol transfers combining multiple systems



Replenishing and Recharging
Cryogen and Xenon Transfer Technologies

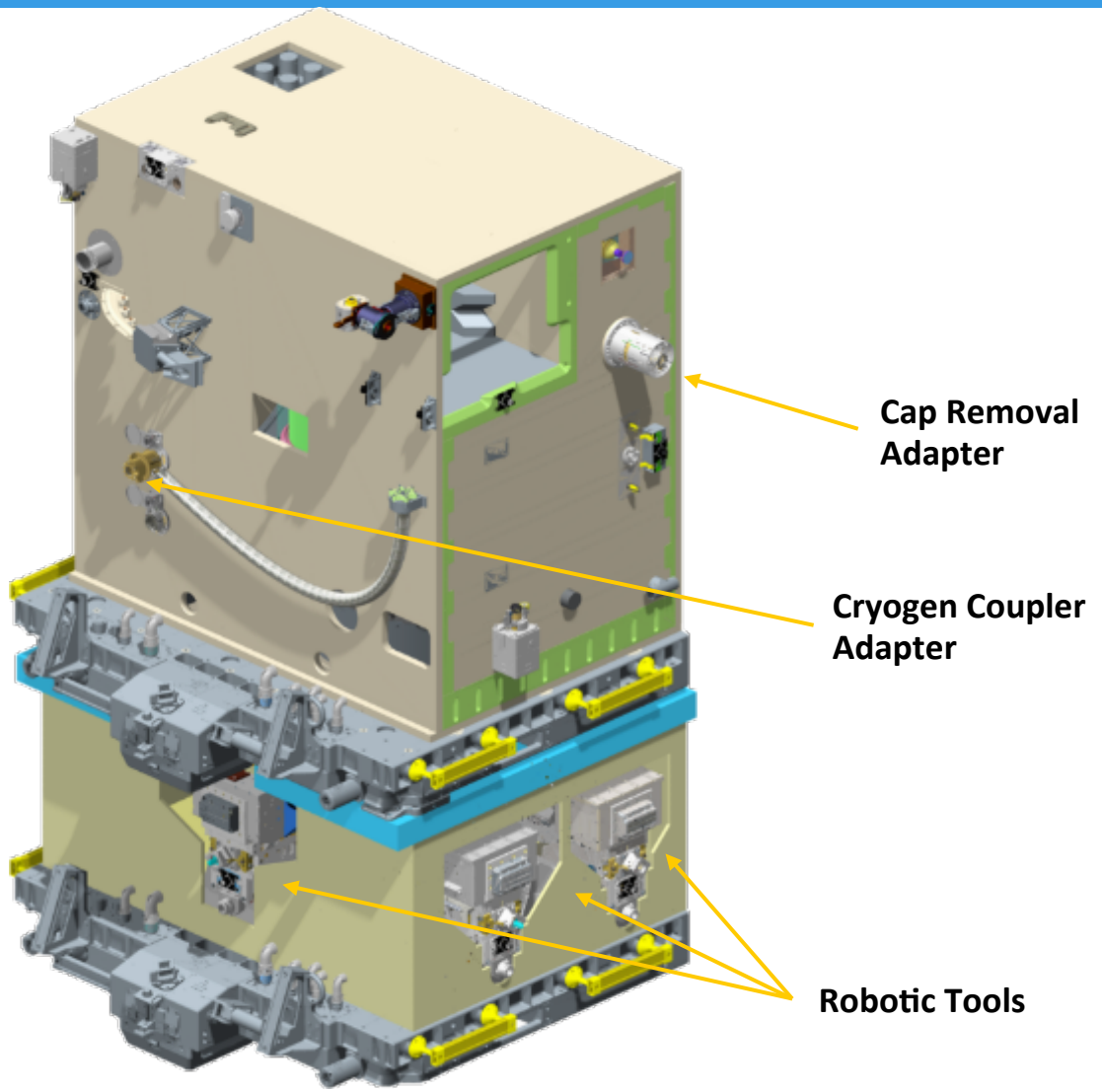
RRM3 is an ISS technology demonstration that will be used to advance the technologies needed for transferring liquid cryogens and xenon gas in zero-g.

RRM3 will feature two fluid transfer systems that will utilize multiple tools and interfaces to transfer the fluids:

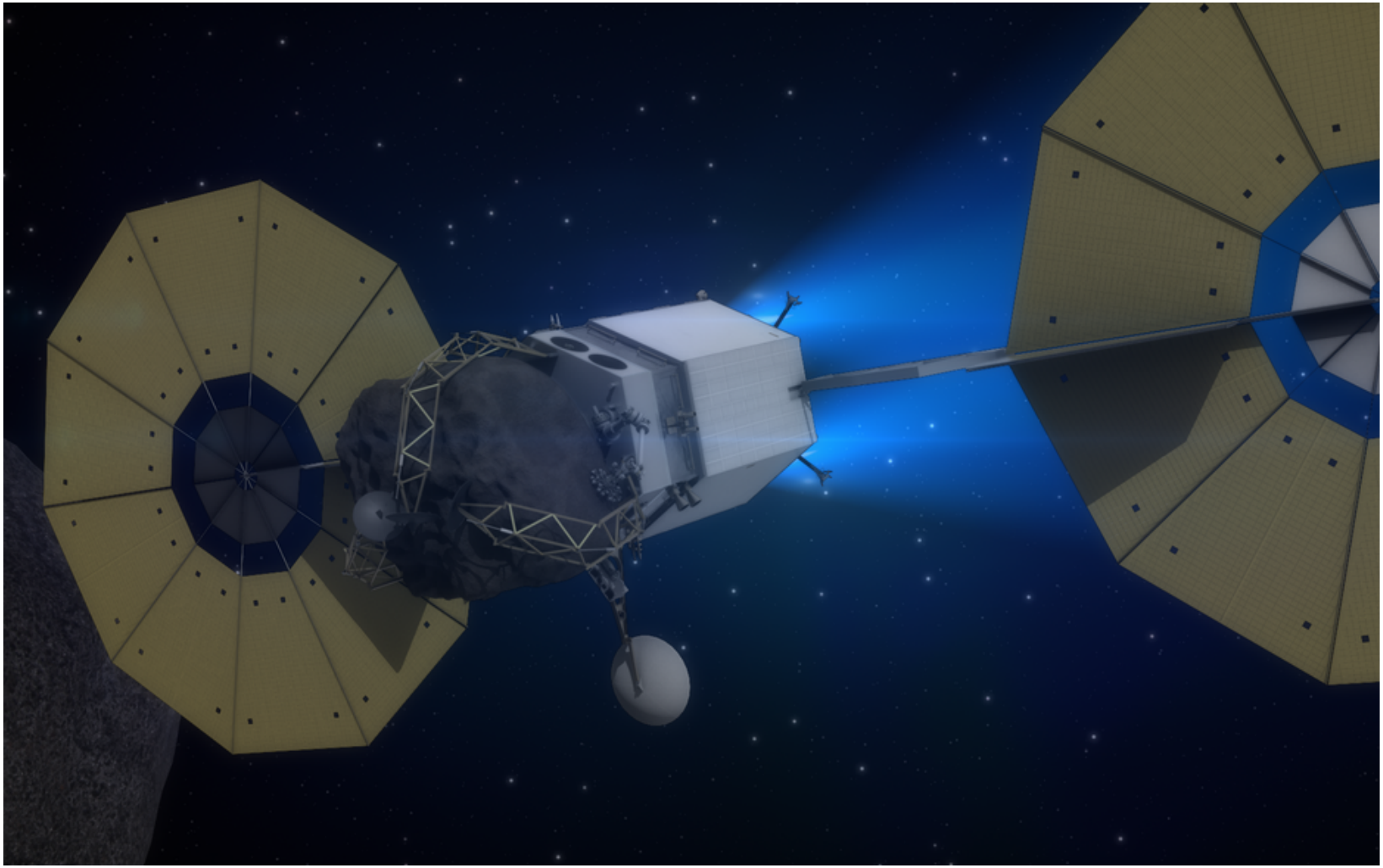
- Cryogen Demonstration Subsystem (CDS)
- Xenon Transfer Subsystem (XTS)

The RRM3 payload will host many new technologies including the following:

- Fluid pumping techniques
- Mass gauging
- Advanced tools and adapters



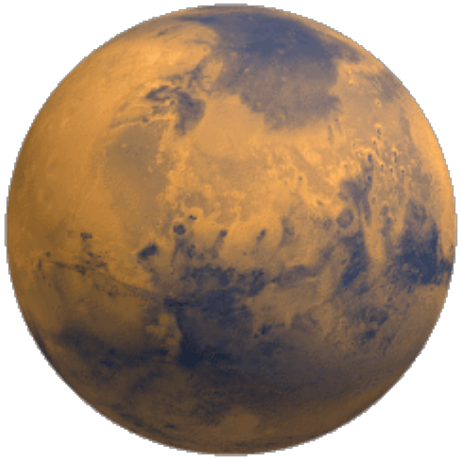
Near-term Opportunity for Xenon Recharge



Asteroid Redirect Vehicle travels to lunar orbit

Conclusion

- **<u>Servicing technologies support Exploration</u>**
  - RPO systems, fluid transfer systems, and accompanying tools serve a critical role in the design of exploration missions
  - A verified servicing infrastructure is being established that future mission planners can leverage



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